Antenna Measurement Instruments And Tools

Antenna design is often regarded as a technological form of arcane sorcery. K1AR takes a look at some tools that we an use to elevate this artform above "black magic."

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While some hams claim that the science of antennas is more akin to trial and error, modern day instrumentation has provided us with a tremendous opportunity to test and prove our theories and designs. In fact, nearly every amateur has had some experience with this subject. You may recall those past ARRL Field Day exercises where you installed your spare SWR meter on the feedline to that 80-meter dipole hanging in the trees. And of course, there is the 10-year-old dummy load you bought at last year's Dayton flea market.

Today's manufacturers offer a wide range of instrumentation products that add "science" to antenna applications—a science that really works when results are interpreted correctly. Critical to successful measurement of antenna parameters, however, is ensuring that the correct instrument is chosen for the job and that it is properly used for accurate results. We will now dispell some of the more common myths and provide an opportunity for you to get the most return from your antenna projects.

SWR Meters

Standing-wave-ratio (SWR) meters are probably the most common antenna measurement instruments found in the ham shack. Simply put, most of us either own an SWR meter or at least have used one. In its simplest form, a SWR meter is an instrument designed to measure the ratio of maximum voltage (or current) to minimum voltage (or current) through the transmission line feeding the antenna load as follows:

If there are no reflections coming from the antenna caused by improper matches, the voltage/current distribution along the antenna will remain constant or "flat." As the mismatch of an antenna varies, reflections or standing wave patterns will begin to occur.

$$VSWR = \frac{1 + \sqrt{\frac{Pr}{Pf}}}{1 - \sqrt{\frac{Pr}{Pf}}}$$

Where: Pr = Reflected Power
Pf = Forward Power

Most SWR indicator circuits use a variation of RF bridge or directional coupler circuits (See Fig. 1). Combined with some form of semiconductor detector to "sample" RF energy through the device, high accuracy can be obtained if care is taken in their construction. Component values and mechanical tolerance are critical to overall accuracy. If excessive heat is used when soldering instrument components, their values may significantly change, distorting results. In addition, physical component symmetry is a critical construction technique. Many of the construction techniques used in commercial SWR Meters are applicable for any RF application, as follows:

- Component values
- Symmetrical construction
- Input/output isolation
- Bridge circuit isolation
- Short component leads

Although there are many commonly used designs for SWR detection, their application varies by the need to maintain constant sensitivity over broad frequency ranges or to support certain power level requirements. Precision and accuracy must also be balance against manufacturing costs for any given unit.

Depending on the application, accuracy may not be a critical factor. For example, many hams need SWR meters for relative measurements (e.g., SWR curves across entire bands where only relative parameters are necessary).

Regardless of design, every antenna has a specific impedance at the feed point. In turn, the best way to match the feed line to the antenna is by measuring the SWR at the feed point, not in the shack. All too often, we are convinced that SWR is good while in the shack, only to discover that the feed point measurement is 2.7:1. The best measure for SWR accuracy while in your shack is to sample your SWR and then change the length of the feed line. Feed lines possessing standing waves will indicate different SWR readings for different lengths of line inserted between the antenna and the meter. These measurements can be especially critical for stacked Yagis, where phasing is an important factor contributing to overall system performance.

Most commercial SWR meters are designed for 50 ohm feed lines. For feed line impedances that differ from the meter's design, coaxial impedance transformers or other matching techniques are essential for measurement accuracy.

RF Wattmeters

Although SWR Meters provide valuable information in ensuring accurate matching of feed lines to antennas/transmitters, they lack the ability to provide

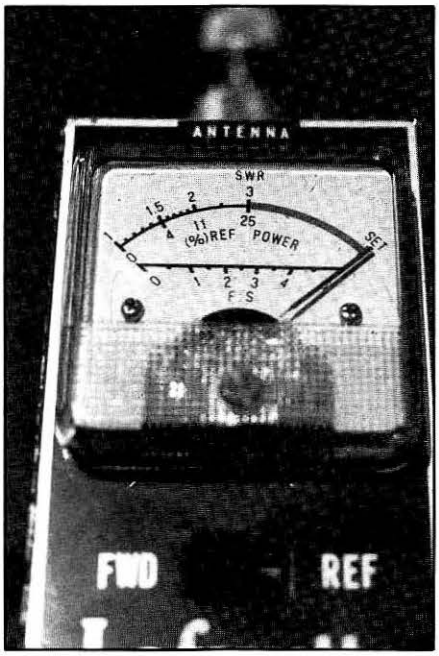
forward/reflected power level information. The RF Wattmeter is a device designed to provide both SWR measurements and transmitter power levels across a broad range of frequencies.

Most commercial designs employ one of two common packaging techniques: a fully encased product or a separate RF head and metering control box. In many cases, it is cumbersome to have coaxial cables connected to an instrument sitting directly on top of your transceiver. Each approach, however, works equally well and its use depends on your specific application needs.

The general idea behind RF Wattmeter designs is to pass the center conductor of the transmission line through a ferrite core. As RF passes through the core, a current is induced into the secondary core winding, which is transferred 180 degrees out of phase into the measurement circuitry at each end of the winding. Matched germanium diodes are most often used as the key components to rectify the sum/difference circuit and transmission line voltages that are ultimately translated into forward and reflected power levels.

The metering approach to inexpensive RF Wattmeters varies, but can be summarized in a few ways. Some manufacturers only provide forward and reflected power readings that are set with front panel switching. This method requires you to perform manual calculations or to refer to charts. A more convenient approach is to provide forward power readings and a direct SWR reading with zeroing adjustment capabilities. Probably the best approach is to employ a "crosshaired" meter that simultaneously displays forward and reflected power and SWR — all on the same meter face. Most inexpensive RF wattmeters have variable scales to adjust for your transmitter output power level. Usually they range from 0-200 watts and 0-2000 watts to measure exciter and linear amplifier applications.

A second type of wattmeter is also available for those requiring a high degree of accuracy or needing one instrument capable of accurately measuring power levels over an extremely broad range of frequency and/or power levels. This design consists of a section of coaxial feedline with an opening for a probe to be inserted into it. A rotational range of 180 degrees allows the probe to measure both forward and reflected power. The probe, usually referred to as a slug, is designed for a specific power range and frequency band. Most such designs use replaceable probes, so it is possible to cover an extremely broad range of frequencies and power levels, depending upon the complement of probes or slugs available.



The most commonly found antenna test device—an SWR meter.

The probe typically consists of a plastic body with a metal cap. Inside, you will find a metal loop that samples the signal within the transmission line. One end of the loop is terminated with a resistor of a value equal to the impedance of the loop. At the other end you will find a diode and, perhaps, a calibration potentiometer. Accuracy is dependent upon the component values as well as the size and relative depth of the loop when the probe is inserted into the transmission line.

These laboratory-grade instruments provide the user with flexibility and accuracy that is unmatched. Although the initial cost of these meters is usually greater than that of other designs, they may ultimately cost less for the user who needs several different power and frequency ranges. All that is needed is to purchase an additional probe. Other designs require an entire separate meter and sampling circuit.

In the final analysis, the accuracy of this system over most others is probably its strongest selling point. As mentioned above in the section dealing with SWR meters, some meters falsely provide different readings on a given reactive antenna, depending where along the transmission line the reading is taken. You can test the accuracy of your SWR or wattmeter by adding a fraction of a wavelength to the length of the transmission line. The laboratory-grade unit will show no change, but most others will.

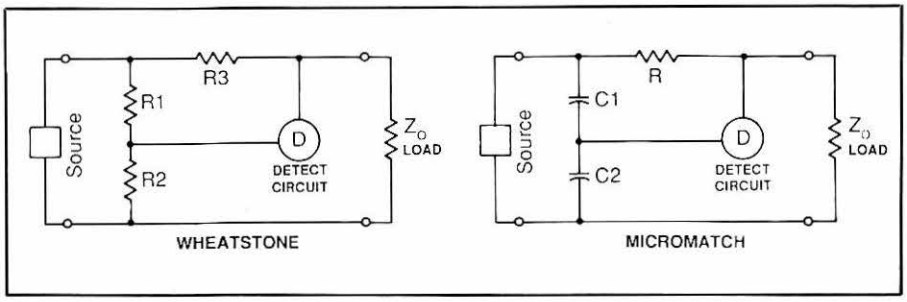
In the practical application of RF Wattmeters, there are several issues to consider. When your meter is being used in a mismatched feed line, you will need to subtract the reflected power from the forward power reading to ensure accurate output power measurement. As with SWR meters, RF Wattmeters are calibrated for a specific line impedance (usually 50 or 75 ohms) and will not indicate accurate power/SWR measurements at different values.

Noise Bridge

An antenna noise bridge is a device designed to allow measurement of unknown impedances. It is of particular value when antenna experimentors attempt to correctly match transmission lines to complex impedance environments (e.g., multi-element verticals, stacked Yagis, etc.). Noise bridges are generally designed in two parts: the noise generator and the bridge measurement circuitry.

The noise generation occurs in the form of a noise source (usually modulated for ease of use) that is amplified to a level suitable to produce a substantial noise level in a monitoring receiver. The noise energy is then coupled into a bridge circuit that measures the unknown impedance and compares its value to known component values within the bridge itself (usually a variable capacitor and potentiometer).

In nearly every case, however, noise bridges are designed to support field situations. This includes battery power, reduced size, and easy connections to re-



The Wheatstone bridge and "micromatch" are two standard designs for SWR bridges.

mote devices (e.g., receivers, antenna sources, etc.).

Noise bridges are designed to indicate the resistive and capacitive/inductive components of an unknown impedance. In practice, a receiver is set to the desired resonant frequency. The noise bridge is adjusted for null condition and the resultant readings can be read off the markings on the front panel. Most noise bridges directly indicate resistive readings and provide a positive/negative measure of capacitance, which can be calculated into an inductive/capacitive reactance figure with these formulas:

$$X_C = \frac{1}{2\pi fC}$$

where: X_C = Capacitive Reactance in ohms.
f = Frequency in MHz.
C = Capacitance in mf.

$$X_I = 2\pi fL$$

where: X_I = Inductive Reactance in ohms.
f = Frequency in MHz.
L = Inductance in μH.

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Obviously, most modern transmitters require a 50 resistive ohms with no reactive component. However, for more complex antenna applications these required values may be different. It is in this application that the noise bridge becomes exceedingly valuable.

Switchable RF Attenuator

The switchable RF attenuator is useful for any application requiring relative measurements, such as antenna pattern measurements and antenna/gain comparisons. As with most antenna measurement devices, RF attenuators (also commonly referred to as step attenuators) are generally designed for 50-ohm circuits and will produce erroneous results if placed in other test environments.

The term "step attenuator" originates from the fact that these devices allow the user to select a series of attenuation "steps," usually in 1-dB increments ranging from 0 dB up to 90 dB or more of signal reduction. RF attenuators are built in enclosures with isolated sections. Great attention is given to isolation between stages and overall signal leakage (especially when supporting amounts of attenuation greater than 70 or 80 dB). It's important to note that very few RF attenuators support high Rf power levels and are typically limited to receiving circuits.

A key advantage of RF attenuators is the independence they provide from more traditional S-Meter measurements in today's transceivers. While modern tranceivers provide fairly good S-meter accuracy, they are especially vulnerable at the higher end of the scale (readings greater than S-9), which is often a limiting factor with local stations. Many transceivers now include limited step attenuation capabilities—usually in 10 dB increments. Although this has some value for certain kinds of antenna tests, it's primary intent is to reduce receiver front-end overload from local signals or broadcasting stations.

In an experiment involving RF attenuators, most researchers start by establishing a reference signal strength on the S-meter of a receiver, such as S-9. If they are attempting to measure antenna patterns, test points are first established. Usually these are in 10-to 15-degree increments and should begin at the null portion of the antenna's pattern. That will enable them to return the S-meter reading to the baseline reading by adding attenuation steps.

As the antenna is rotated, a constant transmitted signal is sent. At each test point, the receiving station adds a measure of attenuation to return the incoming signal to S-9. The result, when plotted over 360 degrees, is a highly accurate data set which indicates the front-to-side, front-to-back ratios, beamwidth, and other useful information necessary to analyze overall performance of the antenna being tested.

Field Strength Meter

As the name implies, a field strength meter's purpose is to provide the experimenter with relative measurements of RF in a near-field environment (e.g., close to the antenna source). These measurements, while not quantitatively accurate (hence the term, relative), are extremely useful in determining relative antenna directivity, such as with phased verticals. Some commercial manufacturers provide a chart that allows the user to determine a measure of signal increase/decrease (in decibels), although they recommend additional testing for truly accurate quantitative results.

The key design aspect of field strength meters is their use of tuned circuits that generally require some adjustment, depending on the desired test frequencies for your antenna. This adjustment is often in the form of plug-in coils combined with a variable capacitor/inductor and will vary depending on the device.

Field strength meters typically include a small antenna that is effective in most amateur applications for measuring the presence of RF near the test site. When there is a need for greater testing distances (e.g., far-field testing), an external antenna is usually required for increased sensitivity. For greatest accuracy, care must be given to its polarity with respect to the antenna being tested.

RF Ammeter/Voltmeter

RF ammeters/voltmeters provide a measure of RF current and voltage being induced into the feed line at any given point along the line. Their most common use is at the transmitter end of an antenna feed line, but even this use is a rarity these days. Most meters of this type are designed to be installed "in-line" and are constructed to support full transmitter power levels (1500 watts output). Most RF ammeters/voltmeters are designed for frequencies up to 30 MHz. Special consideration is needed at higher frequencies.

RF voltmeters can be used to confirm theoretical predictions. For example, you may have a need to verify the presence of a high current/voltage point in a transmission line or at an antenna feed point. This may be critical to a specific mechanical design decision (e.g., required spacing between the feed system of a driven element and the boom) or simply provide some insight into your ability to use sup-

port ropes or tape at certain RF "hot" points in the antenna system.

Dummy Load

The dummy load is probably one of the most common devices found in the average amateur's shack. A dummy load is nothing more than a 50 ohm non-reactive load that simulates a perfectly matched transmission line. Dummy loads are usually constructed with high-wattage non-inductive resistors that are immersed in oil for proper heat dissipation. Some of the earlier dummy loads used cancer causing PCB products (as did some transformers), and should be discarded at an appropriate disposal facility equipped to handle such dangerous chemicals. Testing/destruction of your dummy load is advised if you are unaware of it's condition.

Dummy loads are used for both transmitter and receiver testing. For transmitter tests, you need to ensure that your load is able to dissipate the anticipated level of power radiation. Many commercially available products are rated at normal amateur legal limits, although they may have duty-cycle restrictions. Dummy loads are also useful for receiver testing when you need a 50-ohm load that simulates a "real" load, but does not couple external noise and signals to the receiver.

Glossary

Beamwidth: A measurement in degrees for directive antennas that compares the width of the antenna's major lobe at it's maximum and predetermined reduced gain point. Usually, beamwidths are defined in terms of 3-dB points, meaning the number of degrees between two directions required for a reduction in radiation strength of 50% or 3 dB.

Bridge: An RLC (Resistive/Inductive/Capacitive) electrical circuit useful in the measurement of unknown impedances. Bridges are usually a key design element in the construction of standing wave meters, and RF wattmeters.

Directivity: The characteristic of an antenna that concentrates RF energy into one or more directions or lobes.

Dummy Load: Device designed to simulate a perfectly matched 50-ohm load. Dummy loads are important when extensively testing transmitters without actually transmitting a signal as well as for some receiver tests requiring a matched load.

Feed Line: Transmission line used to transmit RF energy from the generator (transmitter) to the load (antenna).

Field Strength: Measure of concentration of RF energy present near an antenna or other source of RF transmission. Measurements are typically stated in terms of microvolts/distance (meters/feet).

Field Strength Meter: Instrument designed to measure relative field strength. This is particularly useful for estimating antenna pattern performance and gain characteristics.

Front-to-Back Ratio: Common performance measurement for directive antennas that compares forward and backward lobes. This measurement is usually defined in decibels and is one of many criteria for evaluating antenna performance.

Front-to-Side Ratio: Similar to Front to Back performance measurement in that antenna performance is calculated by comparing the front and side lobes of a directive antenna.

Gain: Major indicator of overall effectiveness of a directional antenna. Gain is usually defined in decibels and is a measure of the antenna's improved performance in it's major lobe (forward direction) when compared to a reference source.

Impedance: The resistive and reactive components of a transmission line, antenna, or circuit.

Impedance Transformers: Technique useful in matching different impedances in an electrical circuit or feedline/load.

Load: Alternative term for antenna/device receiving RF energy from the source or transmitter.

Phasing Lines: Transmission lines designed to simulate precise impedance and phase characteristics for multi-antenna arrays. In particular, phasing lines are used with stacked Yagis and multiple vertical arrays for proper transfer of RF energy to all elements of the system. This is a critical design element for maximum performance and advantage over single antenna systems.

Radiation Pattern: A broad definition of the overall performance of an antenna. Antenna radiation patterns are defined in terms of their directive characteristics (e.g., omnidirectional, bidirectional, etc.) and are commonly represented in graphical terms.

RF Ammeter/Voltmeter: Device intended to measure RF voltage/current present in a transmission line or at an antenna feedpoint.

RF Attenuator: Instrument that allows the experimenter to apply controlled amounts of attenuation (measured in decibels) to a receiving device. This is especially useful for antenna pattern measurements and other comparative experiments.

RF Wattmeter: Instrument designed to measure the RF output power originating from the transmitter source. In addition, most commercial wattmeters include the ability to measure standing-wave ratios.

Source: Opposing concept to the term load, the source is the transmitter/generator in a source-load environment.

Standing Wave Ratio (SWR): A measure of the ratio of forward and reflected voltage along a transmission line. SWR measurements are critical to evaluating the matching efficiency between the transmitter and the load. High standing wave ratios (greater that 2:1) can impact overall antenna performance and may create problems with transmitters and other source equipment. These considerations become increasingly critical at higher frequencies.

SWR Meter: Instrument designed to measure the standing wave ratio in transmission lines feeding external loads. The SWR meter is a useful tool for identifying antenna mismatches and other impedance anomalies.